Real Time Currents in the Harbors of the Great Lakes – A Pilot Project

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Abstract- **NOAA's National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS) is responsible for ensuring safe maritime navigation and supporting efficient water-borne commerce. CO-OPS oceanographic and environmental data sets also benefit the National Weather Service, coastal zone managers, and the engineering and surveying communities. In 2006, a new pilot project was introduced and implemented in the Great Lakes to measure currents in real time, horizontally across the Cuyahoga River in Cleveland, and the Maumee River in Toledo, Ohio. This project provides CO-OPS with a variety of new opportunities to expand the National Current Observation Program (NCOP) to the freshwater environment; to enhance partnerships with the Great Lakes shipping community, City of Cleveland, private industry, and federal agencies; and to test a new platform design for a horizontal acoustic Doppler current profiler developed by the U.S. Army Corps of Engineers, Detroit District.**

The pilots of the Lake Carriers and Lakes Pilots Associations requested assistance with navigating the Cuyahoga and Maumee Rivers where winds affect their transit through narrow bridge spans and around sharp bends. The real-time current data provides the pilots with advanced knowledge of the conditions to be expected while in transit, and thus affording them the opportunity to load the vessel accordingly before committing to the river. The pilots identified the narrowest channel of the Cuyahoga River at the Center Street swing bridge in Cleveland, Ohio as a place where real time current measurements would provide them with a worst-case scenario of current speed prior to entering the river. Another area identified by the pilots occurs as vessels inbound from Lake Erie must transit through a narrow span of a railroad swing bridge on the Maumee River as they approach the Archer Daniels Midland (ADM) pier to offload their grain. Access to the latest six minute record of current speed and direction at ADM represents conditions just beyond the bridge spans and this allows the pilot to plan an approach through this area. The real time data (every 6 minutes) can be accessed by the public through the web on the Great Lakes Online web page (http://glakesonline.nos.noaa.gov/moncurrent.html). The data are also available via NOAA's Interactive Voice Response System at 301-713-9596.

Data collection of current speed and direction started in July 2006 and continues to the present at both sites. A persistent pattern has been noted at the Cuyahoga River site where a seiche oscillates approximately every 1.5 hours unless sustained winds compromise the current flow. Flow is either inbound or outbound (towards the lake) at approximately 0.8 knots. There isn't a real-time water level station upstream of the Center Street swing bridge on the Cuyahoga River so an examination of the variation in volume flow from the downstream NOS water level station located in Lake Erie cannot be simultaneously compared to the current data.

A significant feature of the acoustic signal attenuation was noted at the ADM pier last winter when water temperatures approached 32 degrees Fahrenheit. Normal maximum profiling ranges diminished as the temperature dropped and approached freezing. In addition, side lobe interference also increased with the drop in temperature. Other seasonal changes in speed, temperature, and spikes in the data due to wind events are observed as well.

This pilot project may include a third horizontal current meter site at the head of the St. Clair River in the vicinity of the Blue Water Bridge in Port Huron, Michigan in late 2007. Since this project is termed a pilot project, the addition of other current meter sites is dependent on follow-on funding from the US Congress or other sources.

I. THE PILOT PROJECT

One of the primary goals of the National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS) is to support safe navigation. The National Current Observation Program (NCOP) of CO-OPS ensures safe navigation by providing the maritime community with the most up-to-date access to current observations and tidal predictions. Typically, NCOP conducts current surveys of fixed duration utilizing bottom-mounted acoustic Doppler current profiler (ADCP) arrays, subsurface buoys, and horizontally-mounted ADCP's to collect current data in estuaries through which deep draft vessels navigate [1]. As recently as last year, the program was enhanced and expanded to include this pilot project where real-time data are acquired in the non-tidal freshwaters of the connecting channels of the Great Lakes. CO-OPS partnered with the U.S. Army Corps of Engineers (USACE), Detroit District, who developed the engineering designs for these permanent horizontal current meter mounts. Contractors are utilized to fabricate and install the mounts in the rivers of the Great Lakes. Funding for the project was obtained through efforts of the shipping groups interested in maintaining safe navigation through the connecting channels of the Great Lakes. Three sites were identified where advanced knowledge of real-time current speed and direction would assist the pilots with safe passage (Fig. 1) into and out of Lake Erie and Lake Huron. CO-OPS uses horizontal ADCP technology in tidal areas such as the Delaware Bay PORTS at

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Philadelphia (see http://tidesandcurrents.noaa.gov/dbports/dbports.shtml?port=db/). Similar deployments have been successfully demonstrated by others in river systems such as the Sacramento River [2].

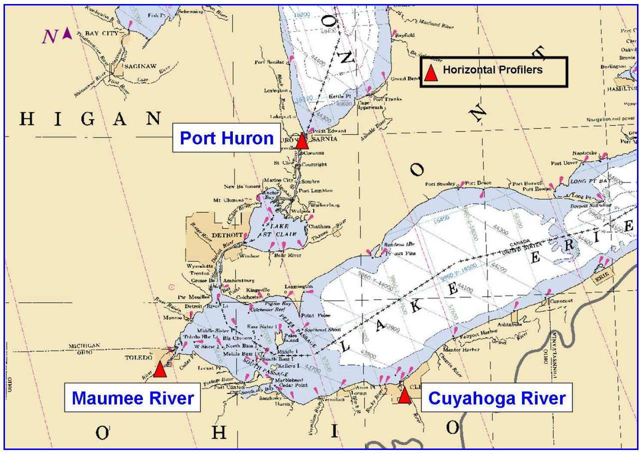

Figure 1. Great Lakes pilot project study area

Current speed and direction, water temperature and water level data are disseminated in real-time every six minutes via the web on the CO-OPS home page at: (**http://glakesonline.nos.noaa.gov/moncurrent.html**) and via the voice system at 301 713-9596**.**

II. THE HORIZONTAL CURRENT METER MOUNT

The USACE Detroit District generated the designs for the permanent mounts utilized in the 2006 NCOP pilot project. The mount consists of dual steel H-beam pilings perfectly aligned vertically with an equal separation top to bottom that are then driven into the river bottom about 10-13 feet and secured to the existing pier structures to provide added stability during winter icing conditions. An adjustable ADCP mounting frame (to which the horizontal current profiler is attached) is equipped with a set of trolley wheels to facilitate movement of the ADCP along the length of the dual H-beams. The profiler is lowered to the desired depth utilizing a winch and pulley system. In addition to the mount, there is an above-water platform that supports the winch and provides safe access to the H-ADCP for troubleshooting, cleaning and routine maintenance. Each mount includes an ice shield that extends above and below the water line to prevent damage to the communication cables and movable tracking system. Power and communication cables from the H-ADCP are tie wrapped to the mount, snaked through the above water platform, and then connected to the communications enclosure box. The communication enclosure system is normally located in close proximity to the platform to minimize the cable length, improve data transmission, and prevent debris from snagging or tangling in the pulley chain or cable.

A. Cuyahoga River Mount and Platform

The pilots of the Lake Carriers Association (LCA) identified a 30 m wide area beneath the Center Street swing bridge in Cleveland, Ohio as an area of interest since passage is restricted to a single vessel (Fig. 2) at a time. The safest location for the horizontal current meter mount was selected in the recessed space at the northeast end of the seawall between the existing pier and circular metal-wrapped concrete dolphin (Fig. 3).

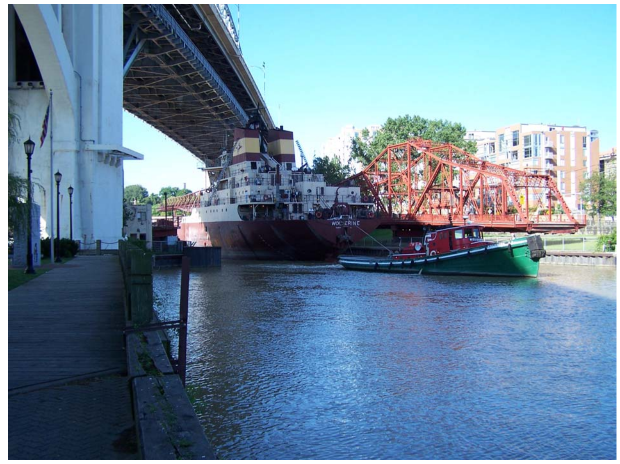

Figure 2. Tug guiding a vessel through the spans of the Center Street swing bridge (red bridge) below the Detroit Superior Viaduct Bridge on the Cuyahoga River in Cleveland, OH on July 6, 2006.

Figure 3. Cuyahoga River platform in Cleveland, OH.

The H-ADCP mount consists of an above water galvanized steel platform with a triangular shaped support for the wire of the winch/pulley system, all of which is surrounded by guard rails. The dual steel H-beams, painted brown in the above figure, are welded to the end of the pier and side of the free-standing dolphin. The white and orange structure (Fig. 3) at the water line in between the H-beams is a delrin plate (discussed in IIIA and shown up close in Fig. 7) that separates the H-ADCP (orange transducers) from the movable steel mounting plate. The Cuyahoga River mount and platform were installed during the week of July 10th 2006.

B. Maumee River Mount and Platform

The Lakes Pilots Association (LPA) identified an area where the river narrows between the bridge supports of a railroad swing bridge just to the north of the Archer Daniels Midland (ADM) grain elevator in Toledo, Ohio as a place of concern during their inbound transit (Fig. 4). A

safe location on that bridge was not possible so an alternate safer site at the ADM pier was selected. This new location allows ships to transit through the bridge spans, dock at the pier without obstructing the current meter, and profile currents that are representative of flow through the bridge spans.

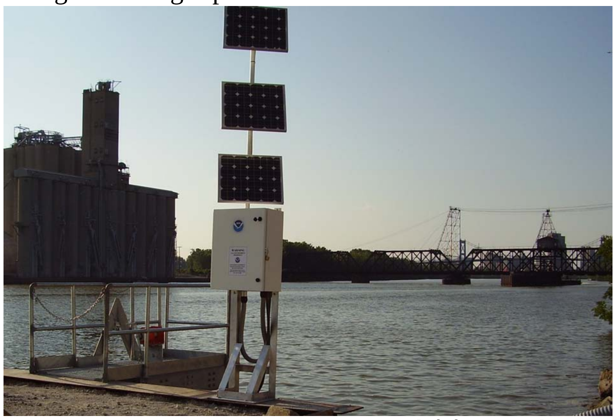

Figure 4. Maumee River current meter station (left foreground), S & W North railroad swing bridge (center right), Kulhman Corp (left center).

The current meter station at the ADM pier (Fig. 4) consists of an above-water platform with winch/pulley system, a nearby data collection system housed inside the white water proof enclosure and 3 solar panels on a 20 ft stand. A rear view of the permanent mount (reddish brown) is visible in Fig 5. The mount consists of dual steel H-beams slightly recessed from the front of the pier and welded to the northeast end of the pier. Currents are profiled perpendicular to the flow of the main ship channel. Flow within the main ship channel aligns with flow along the face of the pier (left to right in Fig 5).

Figure 5. Rear view of the Maumee River platform in Toledo, OH.

The Maumee River mount and platform were installed during the week of June 26th 2006. Some site enhancement to the northeast end of the pier was completed after the mount and platform were operational.

C. St. Clair River Mount

The horizontal current meter mount at the head of the St. Clair River was not yet installed by the time of this manuscript. The international community, including vessel operators and managers, identified a key location beneath the Blue Water Bridge as an important site for determining flow through the spans to assist in validation of a hydrodynamic model of the Huron to Erie Corridor (HEC). The proposed location for the mount is beneath the seawall

Figure 6. St. Clair River in Port Huron, MI.

just after it starts to curve (Fig 6). This area of the seawall is less likely to have ice build up during the winter thus allowing the sensor to remain in the water year round.

III. THE INSTRUMENTATION

Both of the stations deployed in 2006 have instrumentation capable of profiling current speed and direction at multiple distances. The third station to be installed at the head of the St. Clair River will utilize a long-range profiler capable of profiling current speed and direction 300 meters from the sea wall. A summary of the equipment utilized in the pilot project is presented in Table 1 and discussed in detail in this section.

TABLE 1
GREAT LAKES INSTRUMENTATION

INSTRUMENTATION	CUYAHOGA	MAUMEE	ST CLAIR*
Teledyne RDI horizontal ADCP	600 kHz	600 kHz	300 kHz
IP Modem	yes	yes	
Phone	yes	no	
Communication Package	Locked Enclosure	Locked Enclosure	Inside USCG high security building

* installation estimated to occur in October 2007

A. Horizontal Acoustic Doppler Current Profilers

The Teledyne RD Instruments horizontal acoustic Doppler current profiler (H-ADCP) was CO-OPS preferred profiler for this pilot project owing to its performance in freshwater and capability to profile currents as far as 300 m away.

The 600 kHz H-ADCP deployed at the Cuyahoga and Maumee River stations (Fig. 7) have three beams, a pressure sensor, internal water temperature sensor and a zinc anode. The H-ADCP is deployed upside-down so that the pressure sensor is on the bottom and the zinc anode is on top and is attached to an adjustable steel mounting plate with wheels for adjusting its movement up and down the length of the H-beams. A white delrin plate separates dissimilar metals from the internal ADCP compass. The

H-ADCP and mounting plate are aligned within the mount so that the profiler measures currents along 280 deg in the Cuyahoga and 300 deg in the Maumee. The profilers are configured to measure currents every 4 meters for 10 cells (Cuyahoga River) and 40 cells (Maumee River) from the mount every six minutes with a 5-minute ensemble average and a ping rate of 1 Hz.

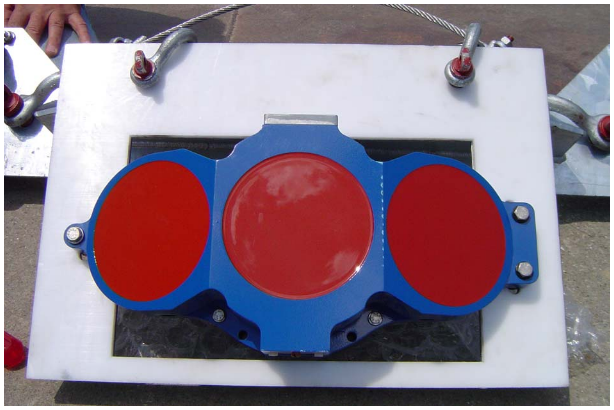

Figure 7. Teledyne RDI 600 kHz horizontal acoustic Doppler current profiler attached to the US Army Corps of Engineers mounting plate.

Beam 1 of the H-ADCP is on the right (Fig 7) and measures current speed and direction towards the south (upstream) and Beam 2 towards Lake Erie to the north (downstream). Beam 3 (center beam, Fig 7) is set to measure currents 90 degrees to the expected flow at the site. The roll of the profiler is adjusted by moving the single and double bolts of the ADCP ears (left and right, respectively in Fig 7) up and down on the mounting plate to attain as close to zero pitch and roll. The entire mounting plate and H-ADCP can be rotated in 5-degree increments over a 30-degree arc to align Beam 3 with the cross current. The roll of the mounting plate and ADCP rely on the vertical placement of the driven steel H-beams. Downstream is reported as positive outbound flow on the CO-OPS web pages.

The 300 kHz long-range H-ADCP, capable of profiling 240-300 m, will be used in the St. Clair River to maximize profiling range. Of course range is dependent on the sensor deployment depth, station depth, and slope to the main ship channel.

B. Data Collection System

Each site is equipped with a locked and weather tight enclosure box (Fig. 8) on a support stand. The enclosure houses the data collection system comprised of an ADCP interface board (top), IP modem (lower left) and antenna, solar panel regulators (center black boxes), 3 12-volt batteries (not shown in Fig 8) that supply power to the ADCP and IP modem and an AC outlet. The Maumee River site in Toledo was originally outfitted with 3 20-inch

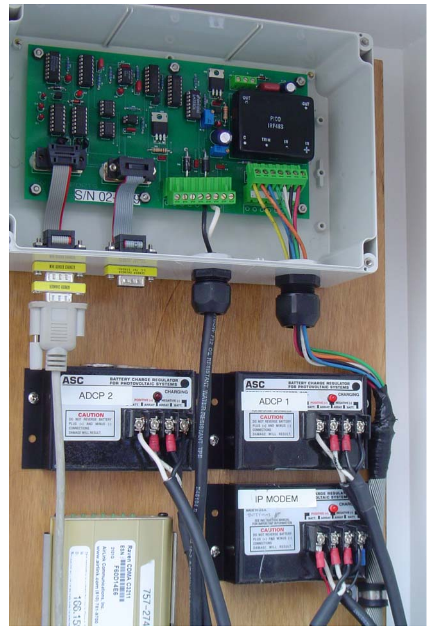

Figure 8. Inside view of a CO-OPS data collection system utilized in real-time applications.

solar panels (shown in Fig. 5) to supplement the 12-volt batteries that power real-time data collection and dissemination. Permanent power to the data collection system was secured a couple of months after installation to ensure data transmission during overcast conditions, nighttime, or when the solar panels were depleted of energy. Phone service was installed as a backup to the IP modem and is implemented whenever data dissemination stops due to loss of cell coverage.

IV. THE REAL TIME DATA

Display and dissemination of the real-time data to the public occurred in early October 2006 after evaluation by CO-OPS and the pilots of the LCA and LPA. Data and station details are summarized in Table 2.

TABLE 2
DATA AND STATION SUMMARY

DATA DETAILS	CUYAHOGA	MAUMEE
Location	41.494483 °N 81.702917 °W	41.629133 °N 83.530217 °W
Station Depth (m)	9.45	5.5
Sensor Depth (m)	4.57	4.2
Start Time*	8/30/2006 01:38 UTC	8/30/2006 02:07 UTC
Cell Size (m)	4	4
Distance to cell 1 (m)	4.93	4.96
Cell #s Reported	1, 3, 6	6, 24

* after firmware upgrade was implemented; allows polling without errors

A. Currents across the Cuyahoga River at the Center Street Swing Bridge

Currents are recorded every 4 meters at a depth of 4.8 m below low water datum from the northeast end of the pier beneath the Center Street swing bridge. Current profiles at three locations across the 35 m wide river began on July 10, 2006 before a firmware upgrade was required on

August 30, 2006. The firmware upgrade allows polling when using the real time mode.

Outbound or downstream flow is to the north towards Lake Erie and inbound or upstream flow is toward the south or head of the Cuyahoga River. A typical 24 hr time series of the current speed at multiple distances from the sensor is displayed on the web (as shown in Fig 9).

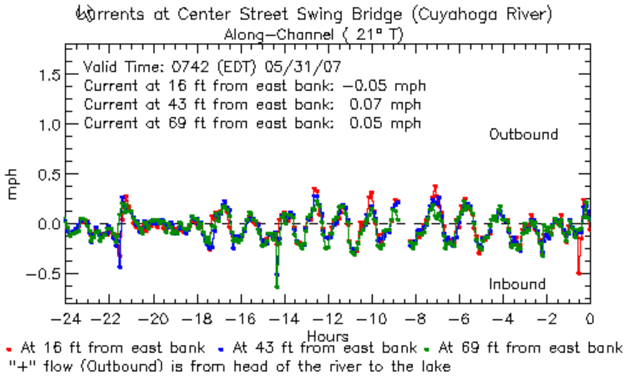

Figure 9. Cuyahoga River currents at Center Street swing bridge.

Note that currents are measured in miles per hour at three locations across the channel for a 24 hr period that ends at 7:42 EDT on May 31, 2007. Fig. 9 shows that currents typically have the same flow from one side of the channel to the other, except when currents closest to the east bank (red dots) are slightly stronger than those on the west bank (see green dots at –7 hr). Small occasional gaps in transmission are shown as white space (see –8.5 hr). Outliers (short fast increases) in current speed may be the result of a large ship's passage through the narrow channel between the bridge supports as shown in Fig. 2. We noted the passage of a sight-seeing vessel that forced more water through the spans every day during the installation of the mount at the Center Street swing bridge.

The Cuyahoga River reverses flow on a fairly regular basis every 0.5 to 2 hours. An interesting observation occurred on June 19, 2007 when there was an influx of warmer water at 2:30 AM resulting in a reversal of current flow (Fig 10).

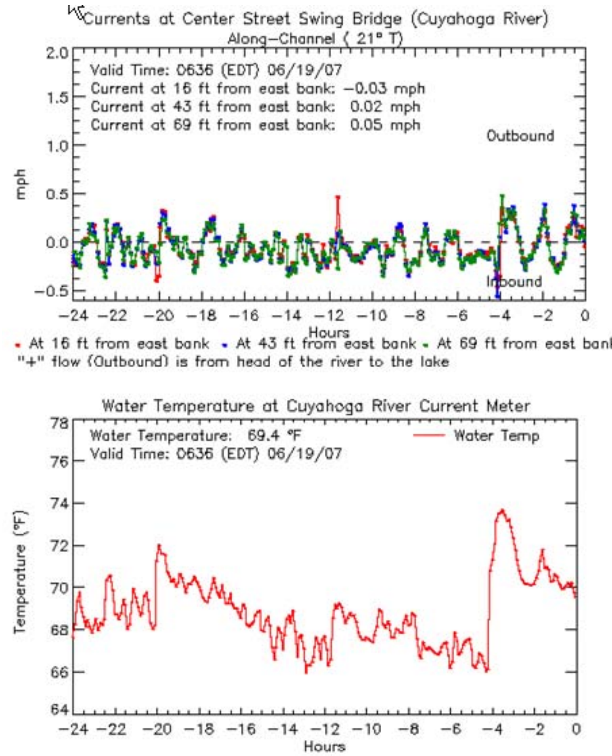

Figure 10. Warm water plume coincides with reversal of currents in the Cuyahoga River.

Current speeds are typically stronger in the shallower near shore water (blue dots) than out in the middle of the turning basin (red dots). Outbound currents flow towards the S&W North railroad swing bridge north of the ADM pier where the pilots have experienced difficult transits when a strong wind blows from the south.

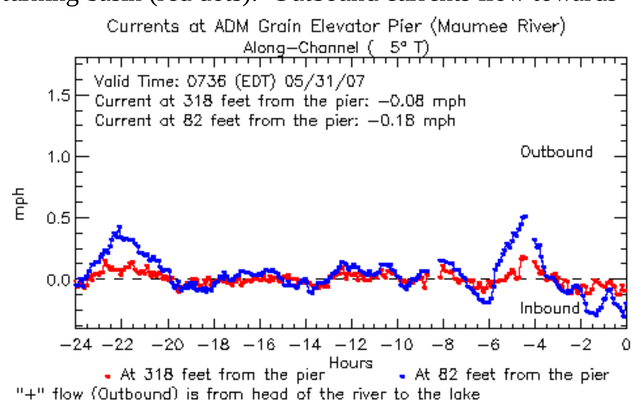

Figure 11. 24 hr time series plot of current data from the Maumee River H-ADCP ending on May 31, 2007.

B. Currents on the Maumee River at the ADM Pier

Currents are recorded every 4 meters at a depth of 4.2 m below low water datum from the northeast end of the ADM pier. Current speed and direction are profiled as far as the middle of the basin and reported on the web at two locations. Current data collection began on June 29, 2006 but complications with polling the data in real time resulted in a firmware upgrade on August 30, 2006. Outbound or downstream flow is to the north towards Lake Erie and inbound or upstream flow is south towards the head of the Maumee River. Current data from near shore (blue dots) and one near the middle of the river basin (red dots) are displayed in Fig. 11. Current speeds in general tend to be greater on the Maumee River than on the Cuyahoga River.

C. Winter Profiling Range

The current profiling range from the Maumee River H-ADCP was affected by the low water temperature and build up of ice during January and February of 2007. A comparison of beam 2 acoustic attenuation during the first summer and winter is shown in Fig. 12.

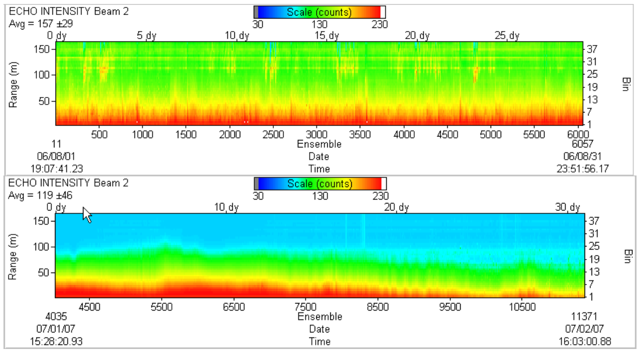

Figure 12. Beam 2 echo intensity contour plots during the summer 2006 (top panel) and winter 2007 (bottom panel).

Normal profiling range during the summer and fall of 2006 is consistently good to a range of 113 meters (cell 28, Fig 12, top panel). The extreme cold temperature and ice formation during the winter (bottom panel) reduced the profiling range to 85 m (cell 21) contributing to side lobe contamination and acoustic attenuation. Beam 2 was selected to evaluate data quality because it profiles currents with the least side lobe contamination while beams 1 and 3 profile +/-15 degrees off center and have higher side lobe contamination. By early February 2007, echo intensity counts had dropped off to 130 in the first 40 m as opposed to 230 counts in August 2006. Soon after the temperature increased and the ice melted, the maximum profiling range returned to 113 meters of consistently good quality data. Temperatures of five degrees C were observed throughout most of January and February. Profiling range increased when temperatures reached 10 degrees C

Winter icing did not occur in the Cuyahoga River and profiling range was not affected. The assumption is made that ice causes reduced profiling range and sonar attenuation.

E. Weather Events and Currents

During the summer of 2007 two weather events had a significant affect on the currents and water levels of the Great Lakes real time stations. The first occurrence (Fig 13), on the evening of May 30th, caused currents (Fig 11) to reverse and increase in speed at the ADM pier in Toledo. The second occurrence (Fig 14a and b), on June 18th, caused the same affect on the currents.

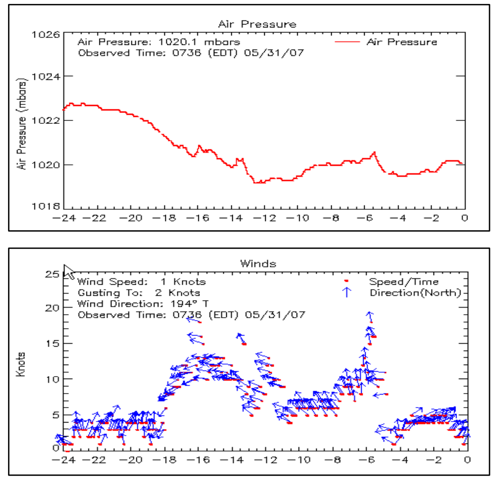

Figure 13. Wind event ending on May 31, 2007 in Toledo, OH.

In the first occurrence, the pressure started dropping about 7:30 PM on May 30, 2007 (at -12 hr Fig 13) and winds from the south spiked to about 12 knots gusting to 18 knots early morning on May 31st. At midnight when the pressure starts dropping, the weak outbound currents begin to reverse (inbound) for an hour. The currents reverse direction again and spike to 0.5 mph at 3 AM when wind gust peak at 18 knots. Outbound currents reverse again and remain inbound at 0.2 mph on May 31 at 7:36 AM.

During the second occurrence on June 18th, the currents increase in magnitude shortly after wind gusts of 12 kt are noted (Fig 14a).

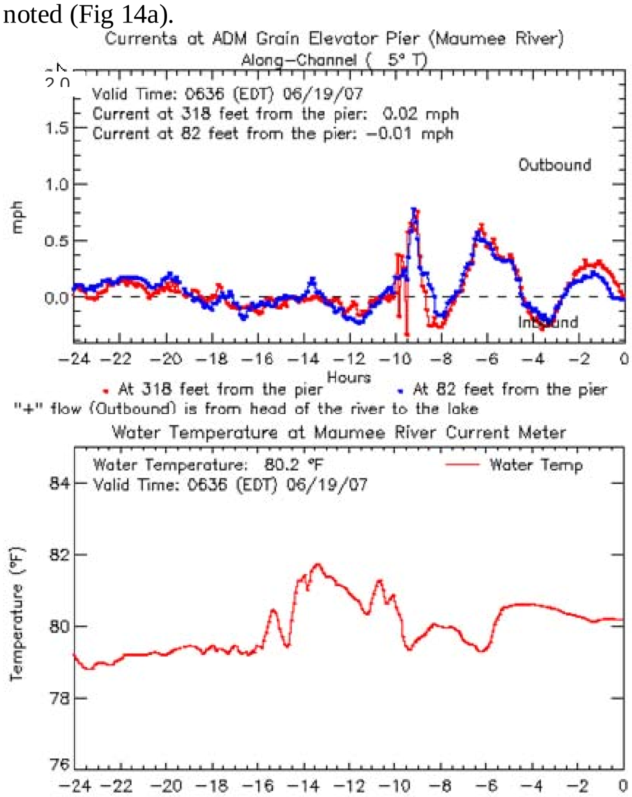

Figure 14a. Toledo storm event ending at 6:36 AM on June 18, 2007. Currents (upper panel) and water temperature (lower panel) at the ADM pier

Wind gusts of 10-12 knots from the southwest persist for about 17 hours beginning at 1 PM on June 18 (Fig. 14b lower panel). This results in a drop of water levels (upper panel) at the tide station located about 7 miles north of the current meter station. About the same time the water level drops, the currents at the ADM pier in Toledo OH start to reverse direction and increase in magnitude (upper panel, Fig 14a).

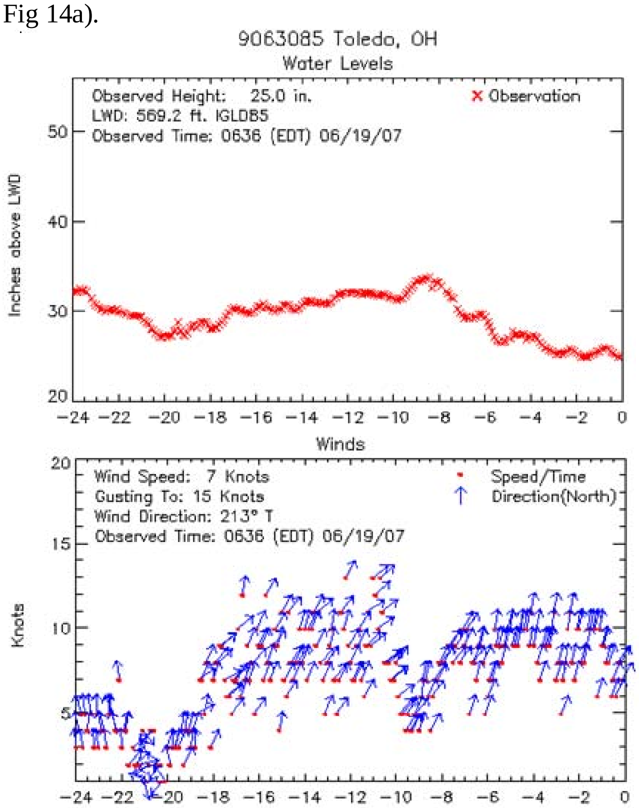

Figure 14b. Toledo storm event ending at 6:36 AM on June 18, 2007. Water level (upper panel) and winds (lower panel).

V. FUTURE PLANS

CO-OPS considers the 2006 pilot project a success and expects to install a third permanent H-ADCP mount beneath the Blue Water Bridge in Port Huron, MI after permission is granted by the Michigan Department of Transportation. The USACE developed new engineering designs for mount at this site. The mount differs from the other two sites by utilizing only a single steel H-beam with all movable parts located below the existing sidewalk on the seawall adjacent to the concrete barrier shown in the upper left portion of Fig. 6. There will not be an above water platform or any visible parts so that the area maintains its natural aesthetic quality. The H-ADCP mounting plate is raised and lowered using a portable davit and winching system. The mount will be recessed into the 'S-shaped' steel sheet pile seawall so that the top of the H-pile is located beneath the existing sidewalk. The above water portion of the mount will be welded in place to provide stability, prevent debris from snagging exposed parts and reduce the potential of in-water hazards to the public's safety. The installation of the mount is expected to occur before the end of 2007. CO-OPS will follow up with the pilots to ensure real time currents have been successful in moving ships in and out of the harbors and connecting rivers of the Great Lakes.

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